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Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Thomsen, J. D., Bøggild, P., & Booth, T. (2016). *Intrinsic roughness in suspended van der Waals heterostructures*. Poster session presented at Carbonhagen 2016, Copenhagen, Denmark.

Intrinsic roughness in suspended van der Waals heterostructures

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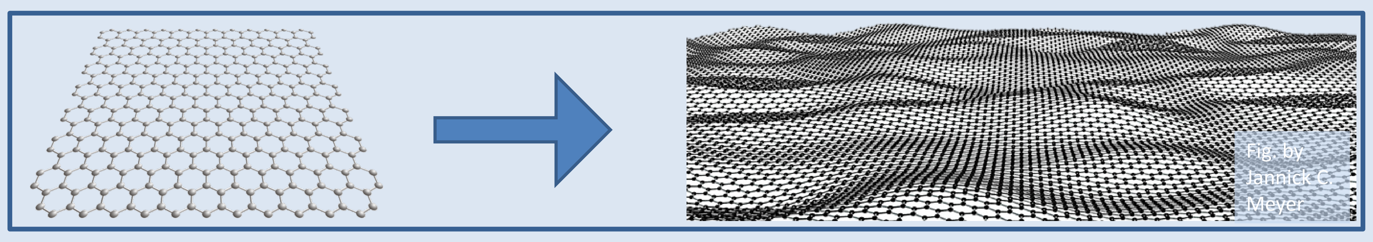
Introduction

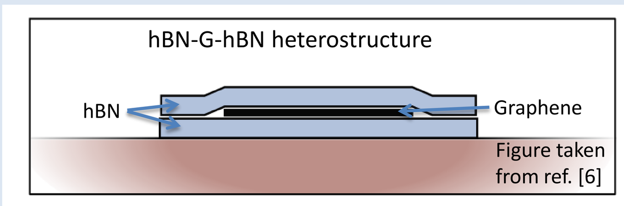
Intrinsic roughness/ripples

- Ripples in graphene are ubiquitous – seen for both for graphene on hBN, SiO2 [1] and suspended graphene [2]
- Ripples may be a large factor limiting electron mobility [3] [4]



Encapsulated graphene

- Making hBN-G-hBN heterostructures is a well known strategy for obtaining high mobility grapene samples
- Measurements of supported graphene on hBN have shown root mean square (RMS) roughnesses around 1.4 Å similar to the roughness of suspended graphene [1]
- Here we show that the roughness can be reduced further by suspending the heterostructure.



Methods – In-situ TEM and Fabrication

Reciprocal space of rough graphene

The full 3D Fourier transform of rough graphene in reciprocal space (u,v,w) consists of a set of cones (Fig. 1)

If the graphene is rough the diffraction spots become diffuse when tilting the sample

For G/hBN samples the spots remain the same

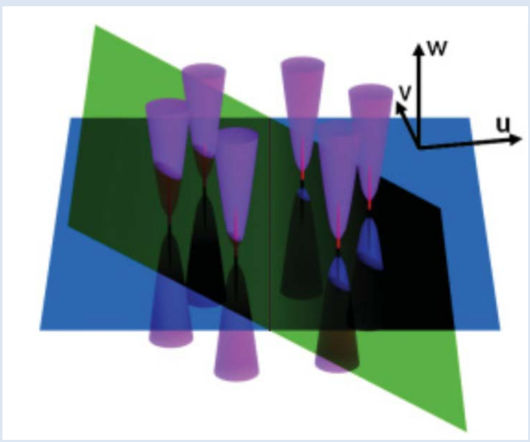


Fig. 1 – the 3D Fourier transform of rippled graphene consists of cones. The green plane represents the Ewald sphere intersecting the density distribution to form diffraction patterns. Figure taken from Ref. [5]

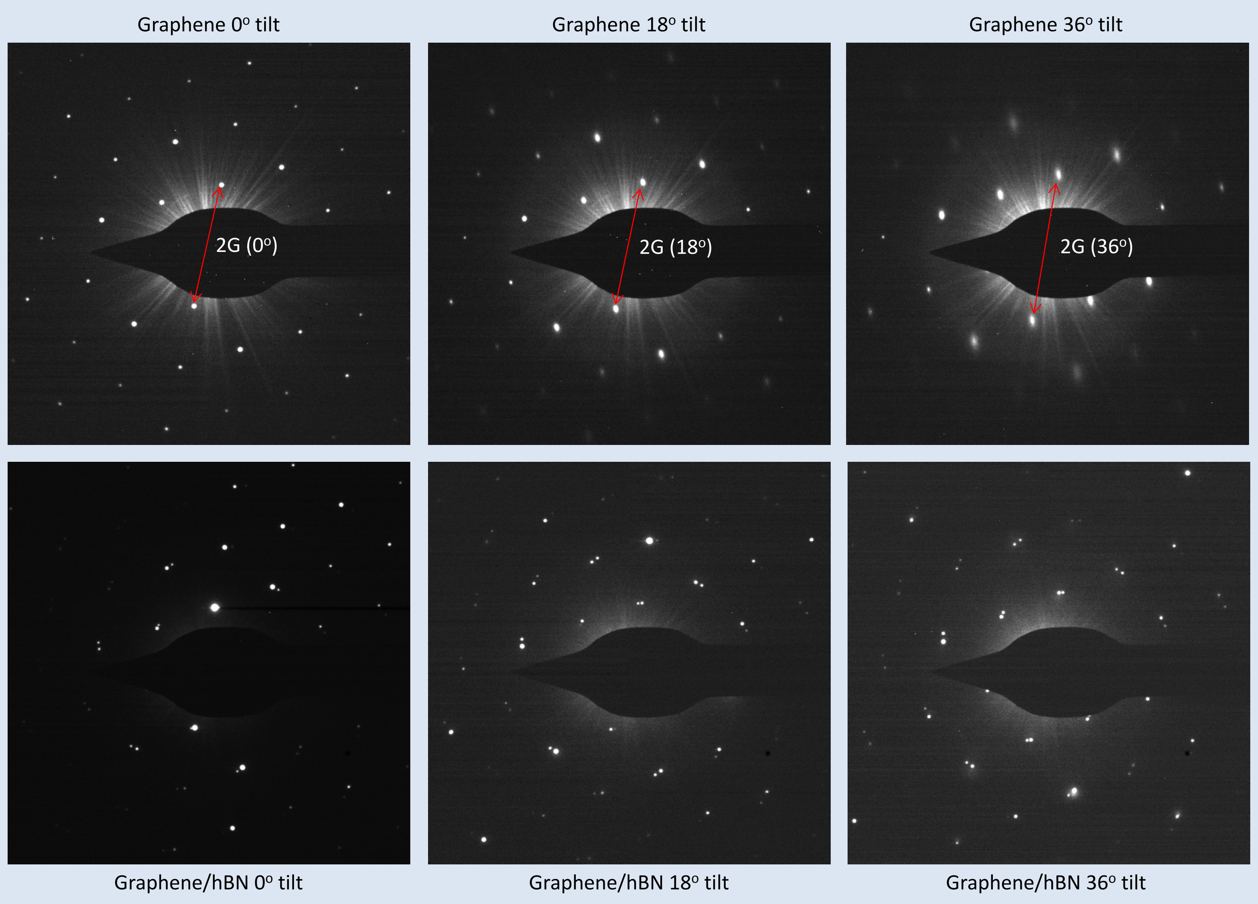


Fig. 2 – diffration patterns of graphene and graphene/hBN at 0°, 18° and 36° tilt.

Roughness

The spot intensity of rough graphene varies as $A \propto \exp(-(2\pi G)^2\langle h^2\rangle)$, where $\langle h^2\rangle$ is the RMS roughness [5]. Hence

$$\boxed{\sqrt{\langle h^2\rangle} = \frac{1}{2\pi}\sqrt{\frac{d\ln(A)}{dG^2}}}$$

Sample fabrication

The samples were made using the hot pick-up method (Fig. 3) [6]

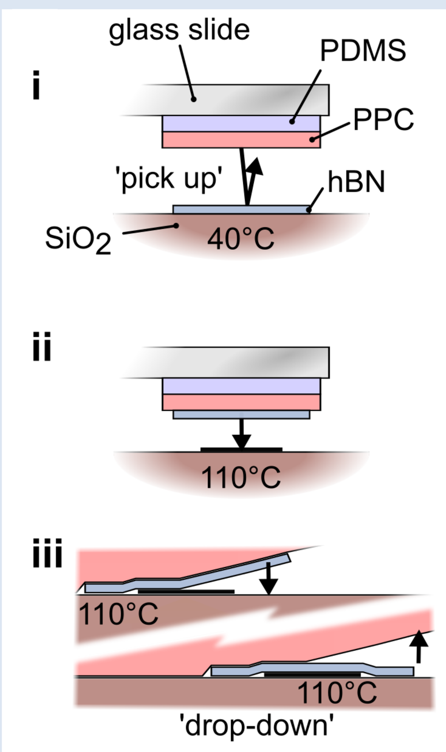


Fig. 3 – Hot pick-up procedure, (i) pick-up of hBN, (ii) drop down on graphene, (iii) release of polymer stack. Fig. taken from ref. [6]

Roughness of heterostructures

The roughness of two BN/G heterostructures and three suspended graphene samples were measured in a TEM.

On one heterostructure sample the roughnes of the suspended graphene part was also measured (Fig. 4)

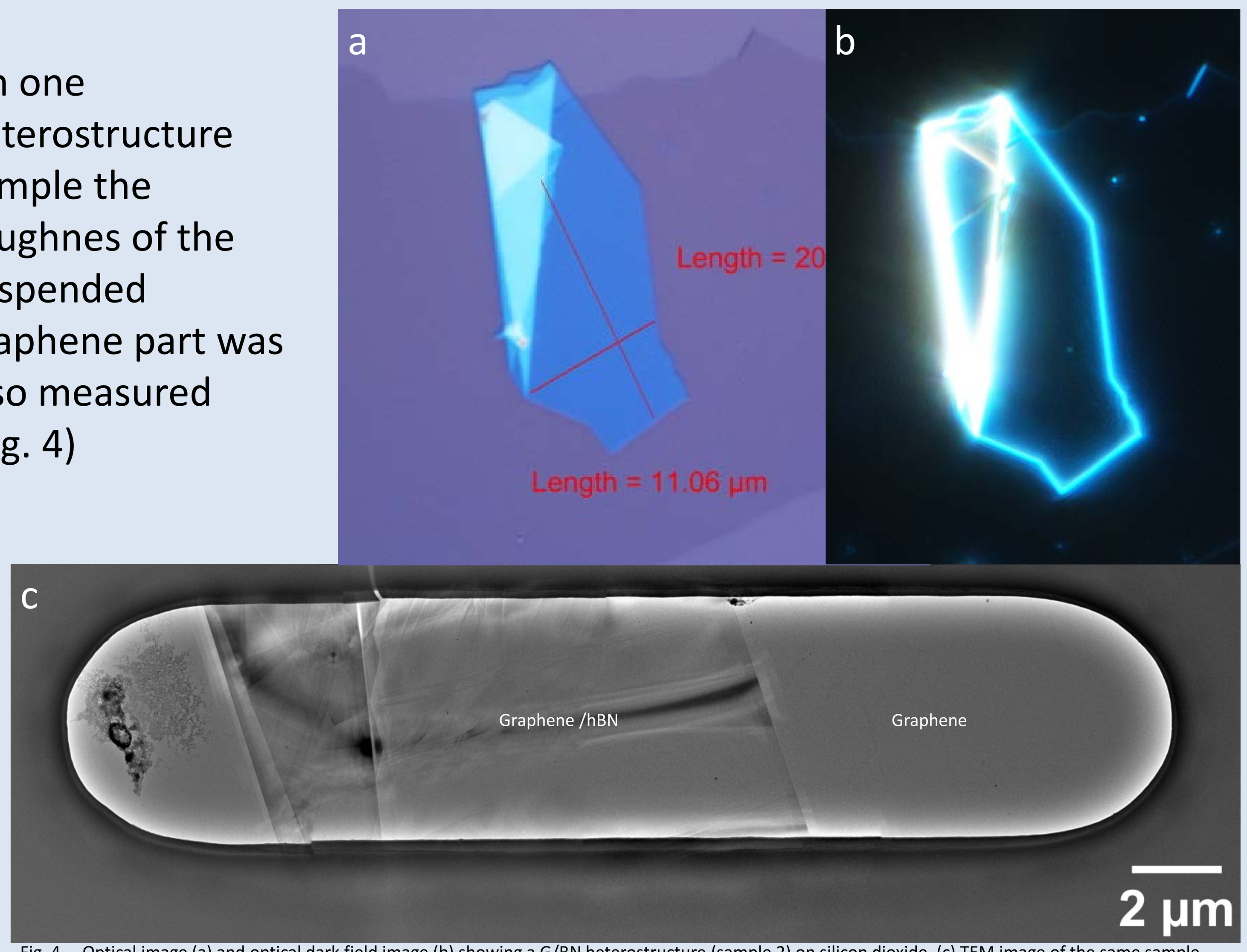


Fig. 4 – Optical image (a) and optical dark field image (b) showing a G/BN heterostructure (sample 2) on silicon dioxide, (c) TEM image of the same sample.

Plots of ln(A) vs. G^2 for the samples are shown in Fig. 5 and the corresponding measured roughnesses are listed in the legend.

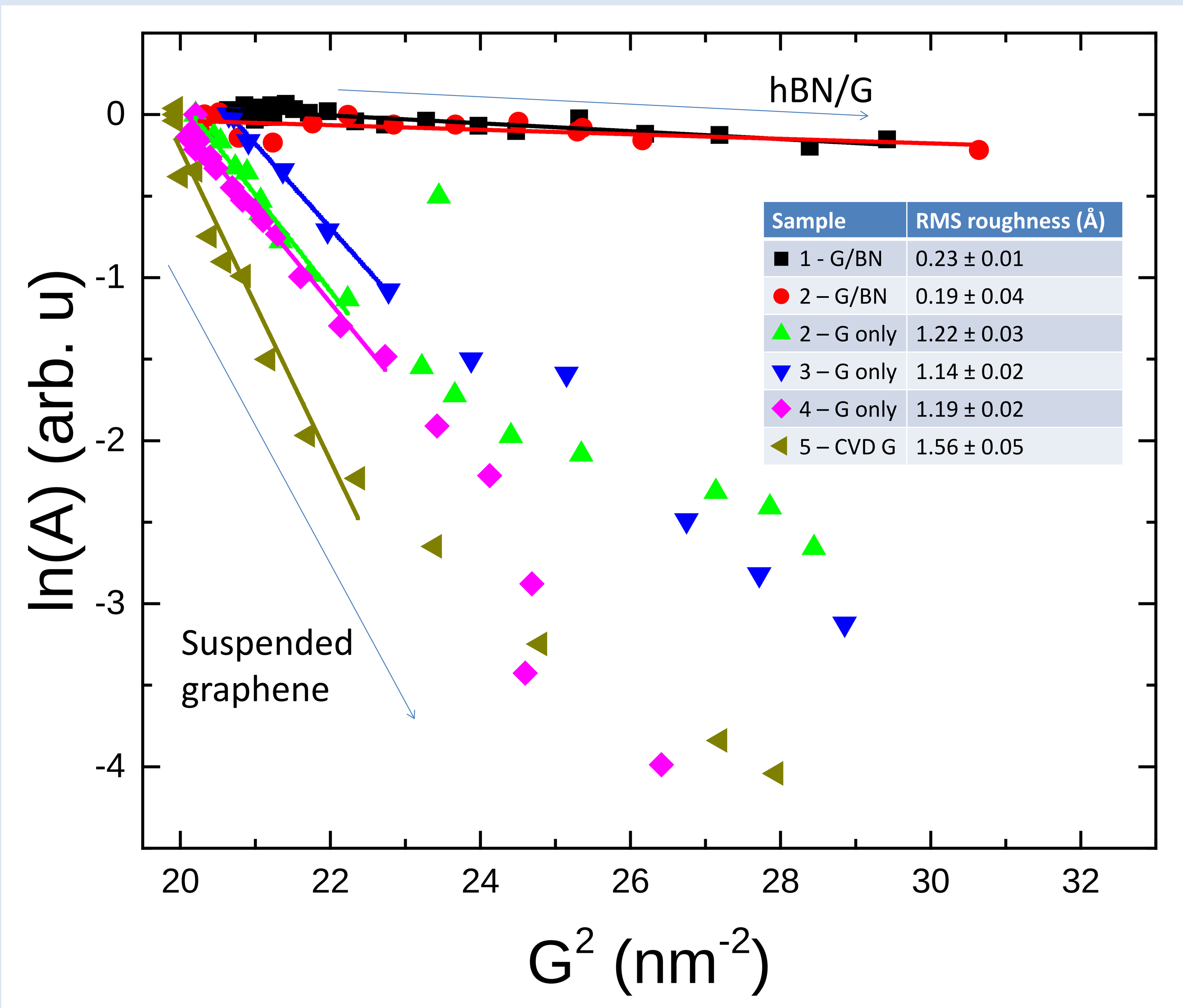


Fig. 5 – plots of the logarithm of the diffraction spot amplitude as a function of the square of the distance from the zero order diffraction spot to the spot center. The slope of the linear fits is proportional to the RMS roughness of the graphene.

Conclusion

- Roughness is possibly the main factor limiting mobility in suspended samples
- Even graphene encapsulated in hBN shows a RMS roughness around 1.4 Å
- By suspending the heterostructures we have measured a significant decrease in RMS roughness – around 0.2 Å.

The work leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° FP7-604000

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